Indirect / Passive Air-Flow Systems

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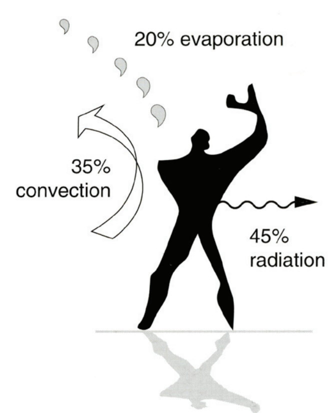
Why Air-Flow Matters

In beginning an investigation into air-flow systems it is helpful to first establish why this subject is important in the first place. There are three major reasons, each compelling in itself and as a group proving that this subject would be unwise to ignore. These three reasons are comfort, energy and health.

Comfort

Air-flow plays a central role in determining the way we perceive the environment, be that outdoors or in. Air-flow is integral to the way our bodies regulate heat. Convection occurs when a fluid (gas or liquid) is heated and as a result moves from one place to another. (warm air rises in a room, allowing cool air to fall). Convection moves warm air away from the body, accounting for fully 35% of the heat lost from the body. Air flow also facilitates evaporation of sweat, further cooling the body, which acounts for 20% of the heat lost. Moving air removes moisture and provides proper conditions underwhich the body can evaporatively cool itself by perspiration. Together these acount for more than half of the cooling capacity.



It is also important to note that air speed has an effect on perceived comfort. Optimal air movement for thermal comfort is 10-50 feet per minute. Lower levels feel stagnant

Velocity		Probable impact
up to 50 fpm	(0,254 m/s)	unnoticed
50 to 100 fpm	(0,254 m/s to 0,508 m/s)	pleasant
100 to 200 fpm	(0,508 m/s to 1,016 m/s)	generally pleasant but cauing a constant awareness of air movment
200 to 300 fpm	(1,016 m/s to 1,524 m/s)	from slightly to annoyingly drafty
Above 300 fpm	(above 1,524 m/s)	Requires corrective measures if work and health are to be kept in high efficiency.

fpm: feet per minute
m/s: meters per second
1 ft = 0,3048 m

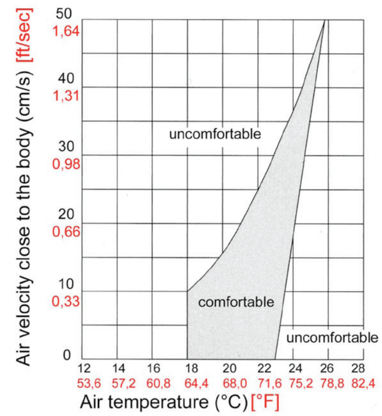


Figure 03: Comfort zone based on air velocity and temperature

and higher levels can be disruptive. (eda pg46) What these quidelines consider comfortable also depends on the environmental temperature, as seen in figure 3.

Energy

Buildings demand a large percentage of the energy produced in this country and around the world. By use building's operational consumption accounts for 38.9% (figure 04) of that produced, which not only contributes to environmental degradation but possibly more importantly for the owners, carries a substantial economic cost. An energy audit of office buildings in the UK comparing naturally ventilated spaces and those that are air-conditioned (figure 05) shows a large difference in delivered energy use between the two types. An even larger difference can be seen in their comparison of primary energy use which looks at the value of energy at its source, accounting for inefficiencies in delivery. This study showcases the possibilities that natural and innovative ventilation strategies can bring to design in the form of cost savings and abatement of environmental degradation.

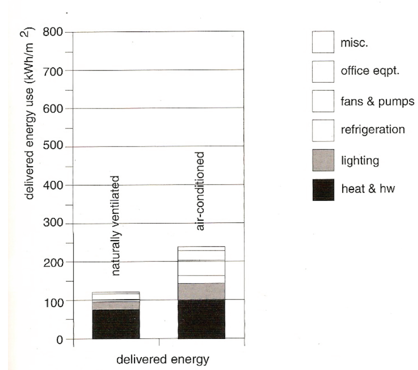


Figure 05: Delivered energy use

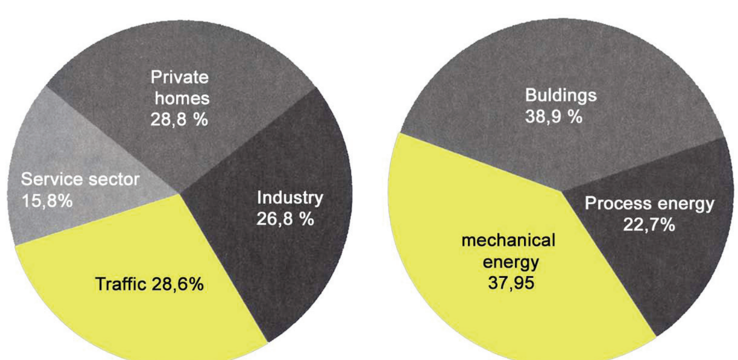


Figure 04: Energy consumption related to user groups and use

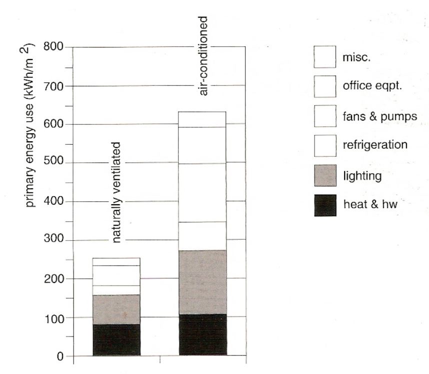


Figure 06: Primary energy use

Health

ncreasingly builders, architects and medical professionals are becoming aware of the prevalence of Sick Building Syndrome in our modern buildings. This group of ailments is largely thought to be the result of prolonged exposure to unhealthy chemicals and compounds in the air due to flaws in the design of heating, cooling and ventilation systems. This phenomenon is a relatively new problem which comes in part from the proclivity to build buildings that allow for almost no natural air infiltration. Today Sick Building Syndrome is most often seen in mechanically ventilationed buildings designed for the minimum level of ventilation. In order to protect against this measures must be taken to ensure appropriate air exchange rates base on occupancy and use of space. Certain guidelines have been developed based on these variables to address this issue. (figure 07)

Necessary outside air flow rates are:

- approx. 40 - 60 m3/h = 1,410 - 2,120 cbft/person for offices
- approx. 20 m3/h = 710 cbft/person for meeting rooms
- approx. 20 - 30 m3/h = 710 - 1,060 cbft/person for lecture rooms and public areas

Figure 07: Air flow rates

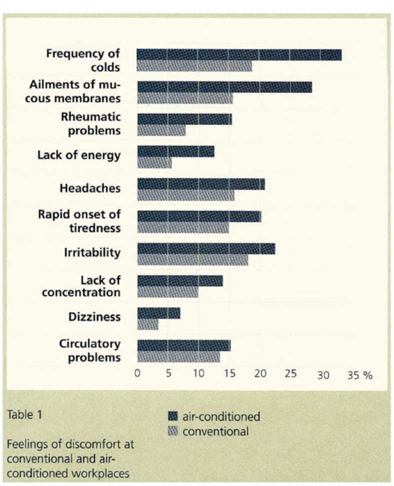


Figure 08: Frequency of SBS

What is Air-Flow?

In order to understand how air flow systems work in buildings it is helpful to begin by exploring the mechanisms that create global atmospheric air circulation. By tracing this thread from global conditions to local and then microclimate we are able to understand how these pieces fit together to affect our buildings. With this information we are better able to decide between competing design strategies.

Global

At the most basic level all air flow is movement from a zone of high pressure to a zone of lower pressure in an attempt of this air to reach equilibrium. The earth's air mass is an incredibly complex and dynamic system in constant flux, but at its base two things drive this system. The first is solar radiation heating different regions of the earth at different rates. This differential heating between the poles and the equator is what creates jet streams and trade winds which act to circulate and equalize this imbalance. The second thing that drives this system is the rotation of the earth, also known as the Coriolis Effect.

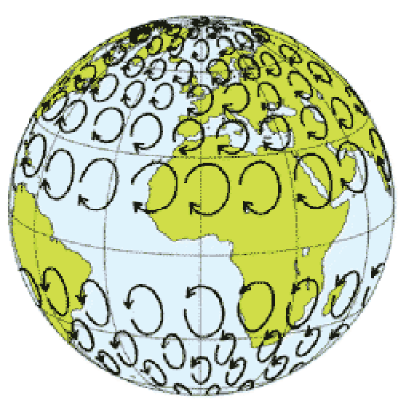


Figure 09: Global air circulation

Local

Local climate data can be very useful for getting a picture of the area's weather patterns. One way this information is sorted in into climate zones, each of which has its own characteristics. While still fairly general, this is a good starting point for determining which environmental strategies will most likely have a chance at success. Below are a few rules of thumb for various climate zones.

- Hot-humid Climates
Maximize natural ventilation. Use large openings and cross ventilation, high ceilings, narrow spaces, single-loaded corridors.

- Hot-Arid Climates
Minimize natural ventilation. Use small air flow openings.

- Temperate Climates
Make dual use of radiation and wind effects, cross ventilation. Use southern openings.

- Cool Climates
Use southern windows, small openings on other exposures

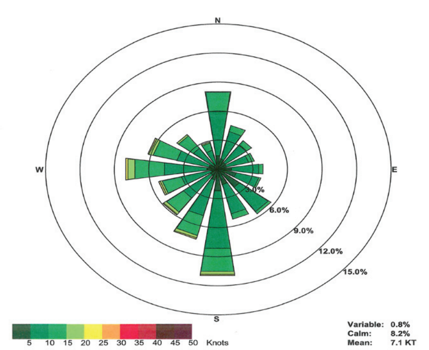


Figure 10: Wind rose

Wind rose data can easily be found which illustrates normal local wind speed and direction for different parts of the year. This information is no doubt useful but it has its pitfalls as an authoritative viewpoint.

Micro-Climate

Micro-climate takes a look at the specific conditions on a given site. At this scale topography and adjacencies to water and vegetation is considered. Recognizing particular configurations inherent in the site can drive many of the important early design decisions. One important feature to be aware of is the cycle of sea and land breezes which move air across land that is close to large bodies of water. In this cycle, as the land heats up, the air around it heat and rises, which draws air inland across the cooler water. Then at night when the land cools more quickly, the opposite happens and air flows from the land toward the water. A diagram of this process can be seen in figure 11. The presence of mountains also has a profound effect on air flow. Mountain breezes can occur when mountains heat up faster than the air at the surrounding altitude, creating an uplift breeze. Mountains and other types of variable terrain can also create wind screens and pockets of turbulence. Additionally the presence of vegetation such as trees and bushes should be considered, as they can be very successful at deflecting wind.

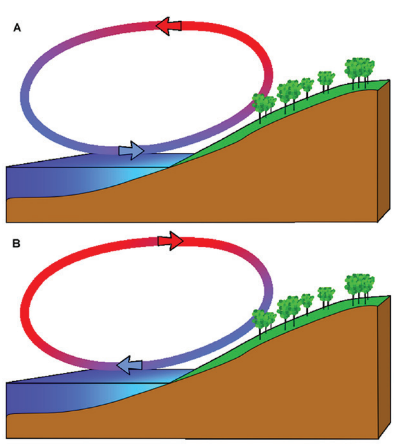


Figure 11: (A)Sea Breeze (B)Land breeze

Principles: Natural Ventilation

As we have learned all air flow is the result of pressure differentials. There are a few main ways that this occurs in relation to buildings. Wind pressure, in which the exterior air flow creates high and low air pressure zones on the building and stack effect in which heat rising on the interior of the building seeks to escape and draw in cooler air. Wind pressure acts on a building in two major ways, the first and most commonly used is cross ventilation. The second is Venturi effect.

Wind pressure

All air flow is the result of pressure differentials. Wind pressure is the result of wind blowing against and/or past a building. Pressures on the building surfaces come from the change in momentum when air is deflected or its speed is reduced.

Positive pressure is created on the windward side and negative pressure on the leeward side, resulting in air flow from positive to negative pressure zones.

Orienting with the long axis perpendicular to the prevailing warm weather breezes produces the greatest pressure differentials

Venturi Effect: The reduction in fluid pressure that results when a fluid

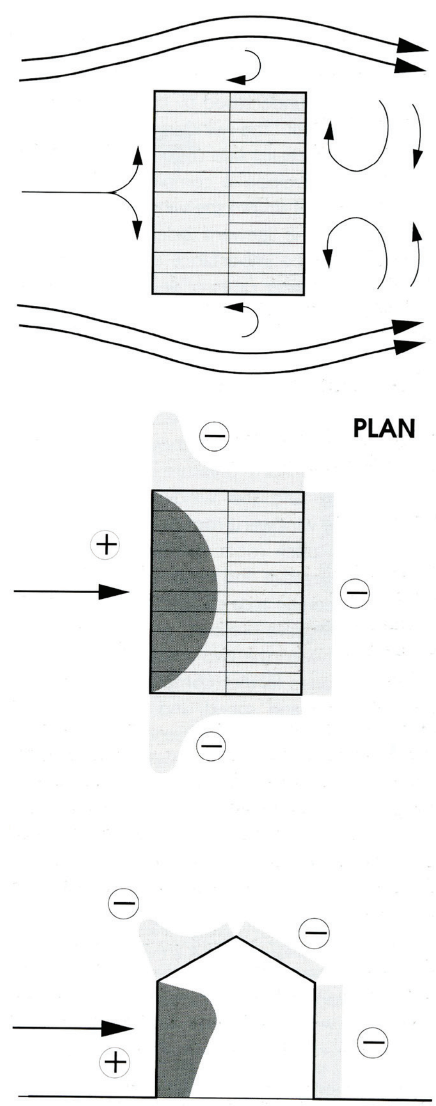


Figure 12: Wind pressure diagram

flows through a constricted section of pipe. The fluid velocity must increase to allow the same volume of air to pass through the constricted opening. The Bernoulli Principle explains the inverse relationship between speed and pressure, meaning that this creates a drop in pressure due to the increase in speed.

This phenomenon can be used to

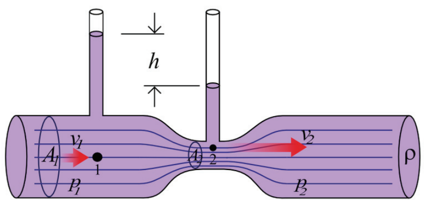


Figure 13: Venturi Diagram

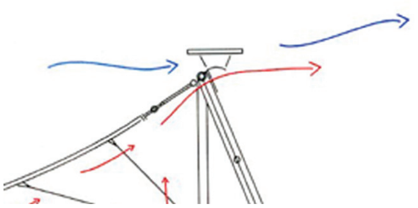


Figure 14: Venturi Effect on Hannover Pavilion

draw air out of a building (usually at the roofline) using the movement of the outside air.

Stack Effect: The molecules of warm air are moving at a faster rate, are more agitated and therefore create more space between these molecules. This means that hot air is less dense than cold air, making this lighter air want to rise relative to cooler air.

This generates a vertical pressure difference dependent upon the average temperature difference between the column of warm air and the external temperature and the height of the column of warm air. This causes warm air to tend to flow out of opening at the top of the building and draw in air near the ground.

This effect is at its maximum in the winter when the greatest temperature differences exist and

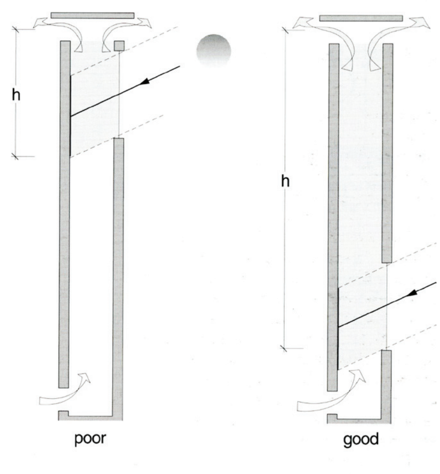


Figure 15: Stack Effect Configurations

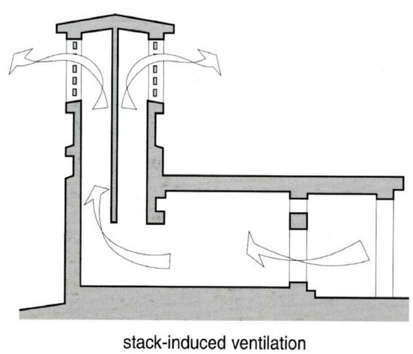


Figure 16: Stack Effect diagram

Factors to Consider for Natural Ventilation

Ventilation systems using only natural forces such as wind and thermal buoyancy need to be designed together with the building, since the building and its components are the elements that can reduce or increase air movement as well as influence the air content.

Qualitative information includes calculation techniques for defining climate parameters. So, design guidelines and criteria for natural ventilation include recommendations and rules like the followings.

Building Location and Layout
- Mountain and hill sites
- By the sea, a lake or a large river
- Urban site

Landscape Design
- Wind deflection
- Funneling and acceleration of air

The Form of the Building Envelope
- Building Height.
- The Roof Form
- Aspect Ratios
- The Corrugation of the Building Envelope

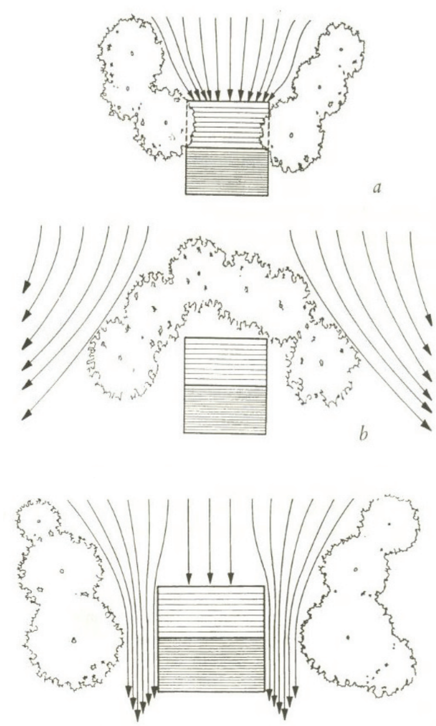


Figure 17: Narrowing of spacing between windbreaks and a building to accelerate the airflow

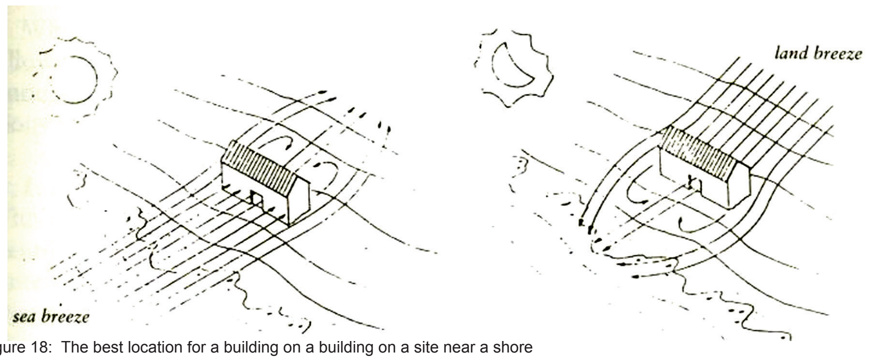


Figure 18: The best location for a building on a building on a site near a shore

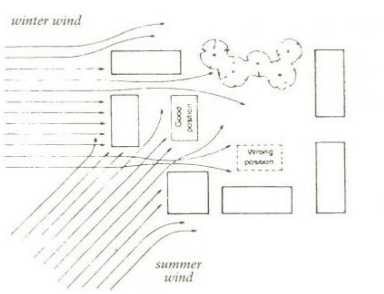


Figure 19: Example of good and bad locations of a building on an urban site, with respect to wind

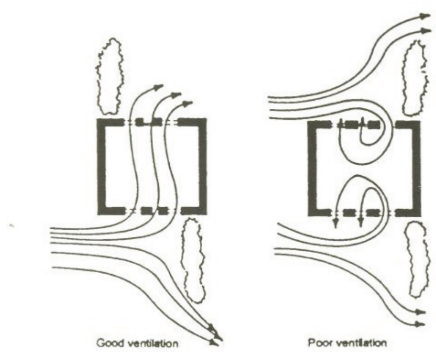


Figure 21: The effect of hedge positioning on the airflow pattern through a building, in the case of wind parallel to the wall containing windows (a similar pattern can be foreseen for a wind direction with and incidence angle of 30')

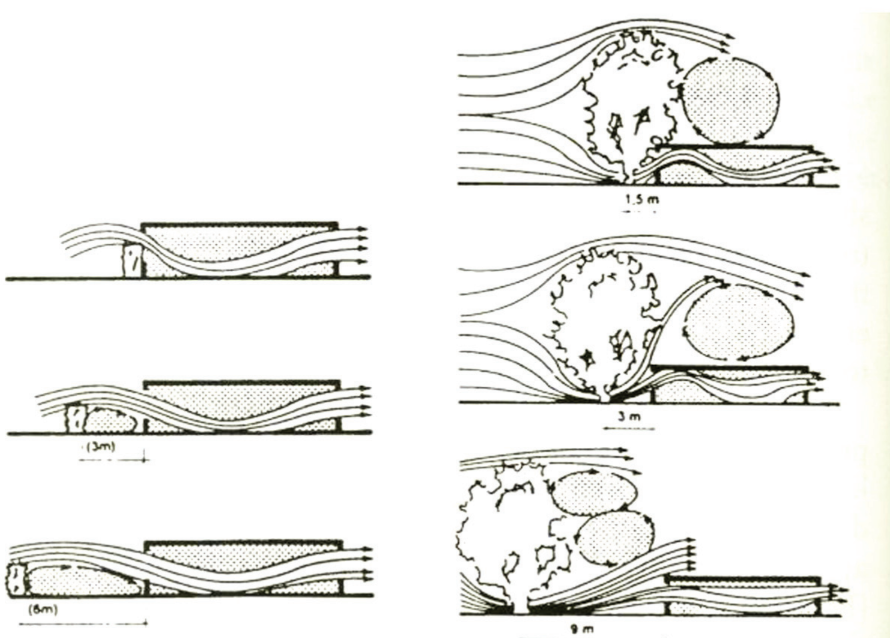


Figure 20: The effect of a hedge(left) and a tree with large base canopy (right) on the airflow pattern through a building relation to their distance from the windward opening

Empirical Models

Simplified empirical models offer general correlations to calculate the airflow rate, or the mean air velocity in the zone. These expressions combine the airflow with the temperature difference, wind velocity and possibly a fluctuating term in order to give a bulk evaluation of the airflow rate or the air estimation of the airflow rate or of the mean air velocity. Several simplified procedures based on empirical data have been developed to produce estimates of ventilation rates in single zone buildings. These models may be used during the earliest design phase to obtain an approximate value of the airflow rate.

the ASHRAE method

The method requires knowledge of the total effective leakage area of the building, which can either be determined using pressurization/ depressurization techniques or evaluated from below table. According to the method, the bulk airflow rate, Q, in a single-zone building is:

$$Q = A\sqrt{a\Delta T + bU_{met}^2}$$

A is the tot ective leakage area of the building (cm^2)
a is the stack coefficient (m^6h^{-2} cm^{-4} k^{-1})
b is the wind coefficient (m^4s^2 $h^{-2}cm^{-4}$)
T is the average indoor-outdoor temperature difference (K);
U is the meterorological wind speed (ms^{-1})

a = 0.00188 for 1 storey building

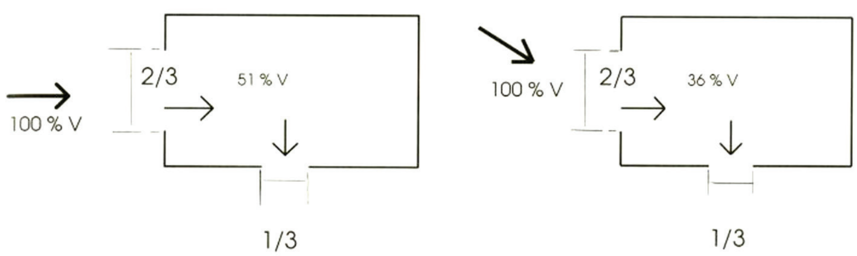
Shielding class	Number of Storeys 1	2	3
No obstructions	0.00413	0.00544	0.00640
Light local shielding	0.00319	0.00421	0.00495
Moderate local shielding	0.00226	0.00299	0.00351
Heavy shielding	0.00135	0.00178	0.00209
Very heavy shielding	0.00041	0.00054	0.00063

Table 1: Coefficient b for various building heights and local shielding classes

a = 0.00376 for 2 storey building a = 0.00564 for 3 storey building

Conditions	Width of aperture/ width of wall = 0.66		Width of aperture/ width of wall = 1	
	V_{avg} (%)	V_{max} (%)	V_{avg} (%)	V_{max} (%)
Single aperture in windward wall, wind direction perpendicular	13	18	16	20
Single aperture in windward wall, wind direction at an angle	15	33	23	36
Single aperture in leeward wall, wind direction at an angle	17	44	17	39
Two apertures in leeward wall, wind direction at an angle	22	56	23	50
One aperture in windward wall, another in adjacent wall, wind direction perpendicular to inlets	45	68	51	103
One aperture in windward wall, another in adjacent wall, wind direction at an angle	37	118	40	110
One aperture in windward wall, another in leeward wall, wind direction perpendicular to inlet	35	65	37	102
One aperture in windward wall, another in leeward wall, wind direction at an angle	42	83	42	94

Table 2: Indoor air velocities for natually ventilated spaces under different wind directions and with different number of appertures an d locations



Conditions for perpendicular to inlet winds	V_{avg} (%)
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1/3	45
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 2/3	39
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1	51
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 1/3	51
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 1/3	50

Conditions for oblique to inlet winds	V_{avg} (%)
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1/3	37
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 2/3	40
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1	45
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 1/3	36
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 1/3	37

Table 3: Effect of inlet and outlet sizes in cross-ventilated spaces; openings on adjacent walls; wind perpendicular and wind oblique to inlet

Methods based on tabulated data

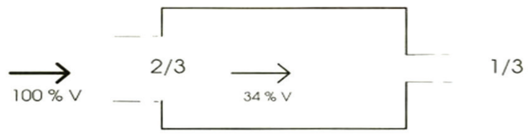
It is well known that the air velocity inside a building is not uniform by any means. Studies in models clearly show draughts and areas of low velocity. However, when judging the overall efficiency of natural ventilation in a building, it is more convenient to consider an average value of the indoor air velocity, V. Melaragno has proposed values of the average and maximum indoor air velocity for two different ratios of the aperture width to the aperture of the wall.

Also, for aligned inlets and outlets and for perpendicular winds, the mean indoor air speed is given in the following tables.

The CSTB methodology

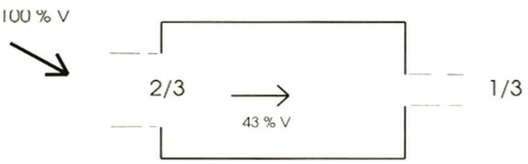
This is based on data obtained from architectural scale models in a wind tunnel for the prediction of the wind-induced indoor air motion. It is based on the evaluation of a ‘Global Ventilation Coefficient’, Cg, defined as the ratio of the mean indoor velocity, V, of the air at a height of 1.5m to the outdoor air velocity, V1.5, at the same height. According to the method, the ventilation coefficient depends directly on;

- the characteristics of site;
- the orientation of the building and the wind;
- the exterior characteristics of the building;
- the interior architecture and the interior aerodynamics of the building.



Conditions for perpendicular winds	V_{avg} (%)
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1/3	35
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 2/3	39
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1	44
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 1/3	34
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 2/3	37
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 1	35
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 1/3	32
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 2/3	36
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 1	47

Table 4: Effect of inlet and outlet sizes in cross-ventilated spaces; openings on opposite walls; wind perpendicular to inlet



Conditions for oblique to inlet winds	V_{avg} (%)
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1/3	42
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 2/3	40
Width inlet/Width of wall = 1/3 and Width outlet/Width of wall = 1	44
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 1/3	43
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 2/3	51
Width inlet/Width of wall = 2/3 and Width outlet/Width of wall = 1	59
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 1/3	41
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 2/3	62
Width inlet/Width of wall = 1 and Width outlet/Width of wall = 1	65

Table 5: Effect of inlet and outlet sizes in cross-ventilated spaces; openings on opposite walls; wind oblique to inlet

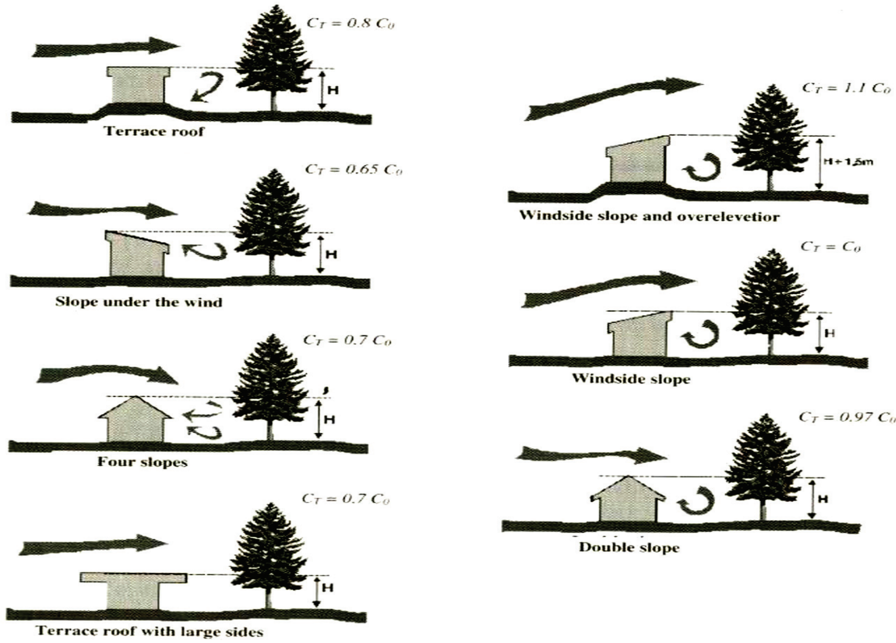


Figure 22: CSTB-the impact of the exterior characteristics of the building: the effect of the roof

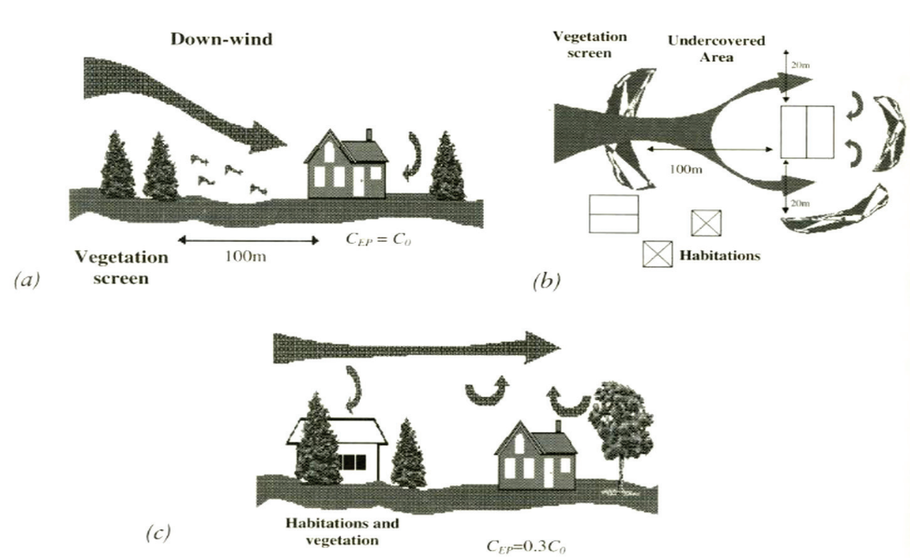


Figure 23: CSTB-the impact of the site: the influence of the surrounding environment

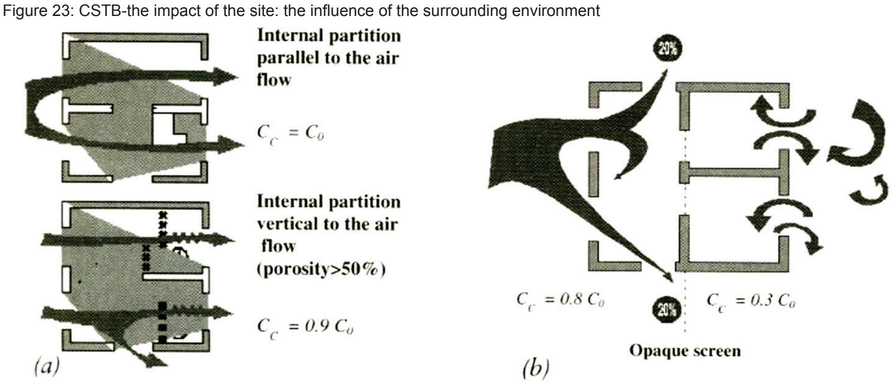


Figure 24: CSTB-the impact of the interior characteristics of the buildings: the roles of the internal partitions

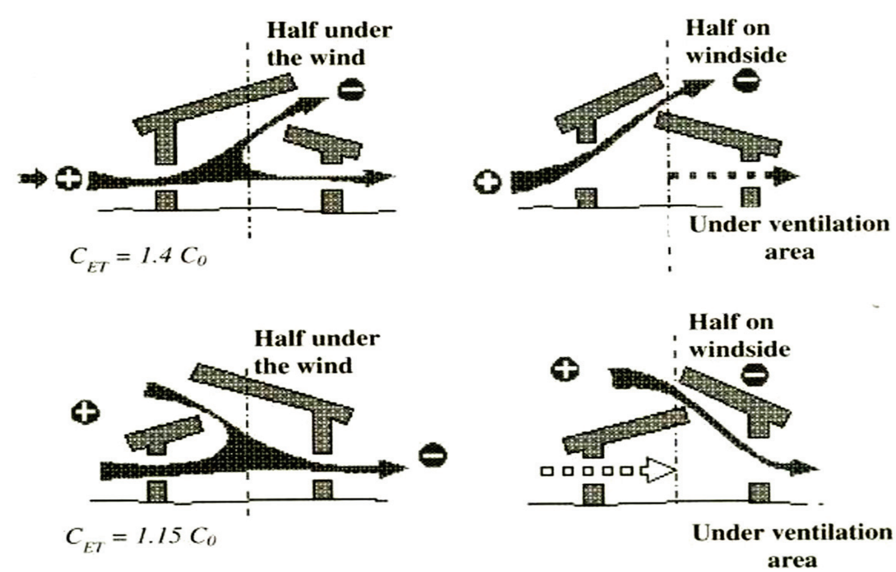


Figure 25: CSTB-the impact of the exterior characteristics of the building: the effect of the open roof

The method therefore proposes the evaluation of four corresponding coefficients,

Cg= min(Csite, Corientation,CArch.Exter, CAero Inter)

So, the diagrams explain, in each case, how the C values are affected by the given factors. These variables show what are the influential variables in each case

- Fig. 22. The shape of roofs
- Fig. 23. The surrounding environment by vegetation and habitations
- Fig. 24. The interior characteristics of the building
- Fig. 25. The location and shape of the open roof

Technologies
Basic Wind-driven Ventilation (Wind Tower and Wind Scoop)

Wind flowing around and across building drives natural ventilation, and can be harnessed in a number of ways. Wind towers can be used to draw air out of the building, subsequently encouraging a natural air flow. Wind scoops can collect and deliver external air to the building, and a combination of wind towers and wind scoops can provide a natural form of air delivery and extraction. Simply using a vertical construct that projects above its surroundings and has an open top, a wind tower is designed. This will ensure negative pressure and provide suction in all wind directions. By collecting and extracting air at high level, rather than through the facades, there will be a greater

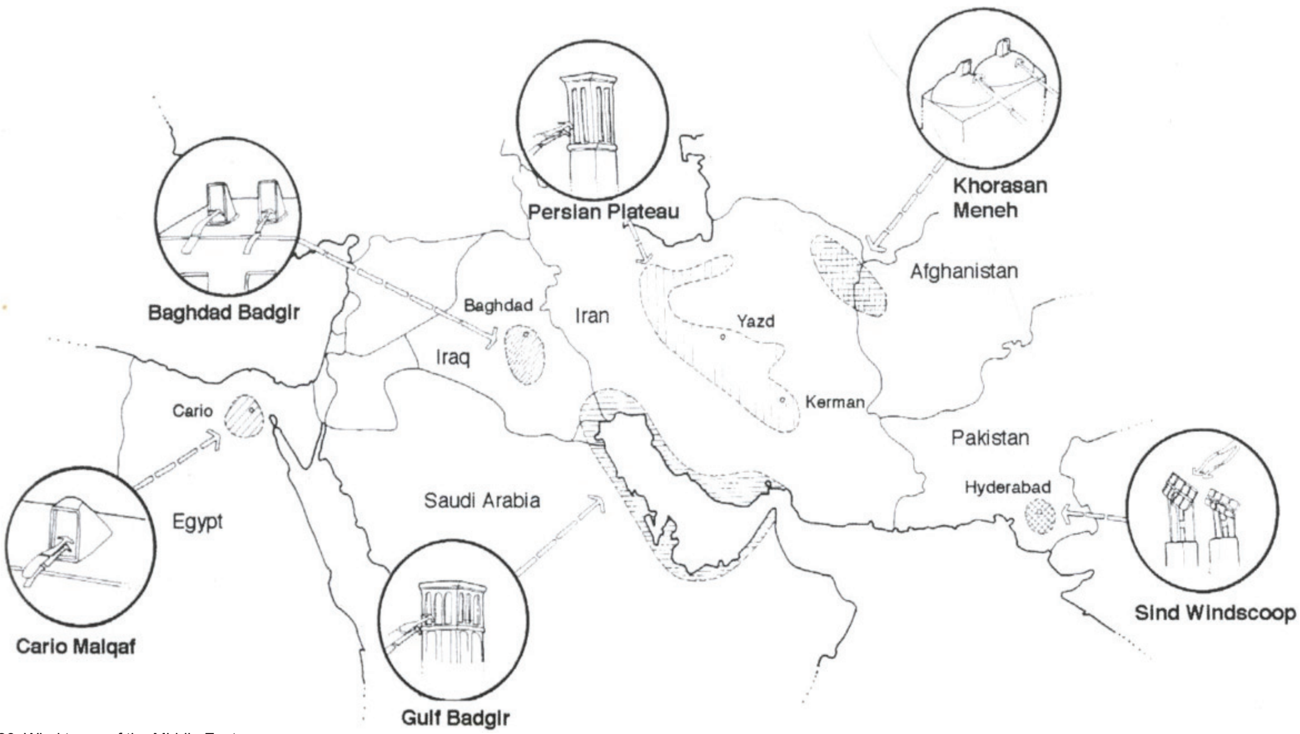


Figure 26: Wind tower of the Middle East

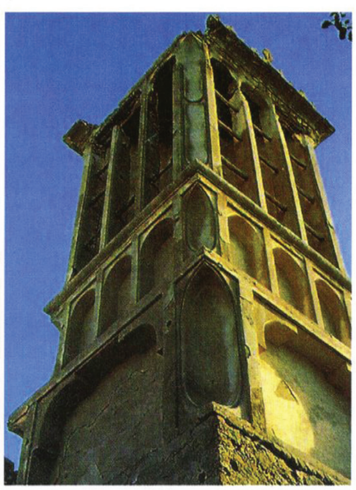


Figure 27: Badgir of Dubai, UAE

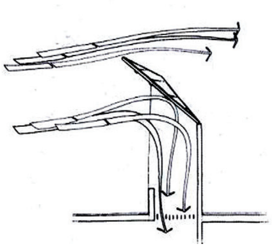


Figure 28: Wind Scoops, Hyderabad, Sind, Parkistan

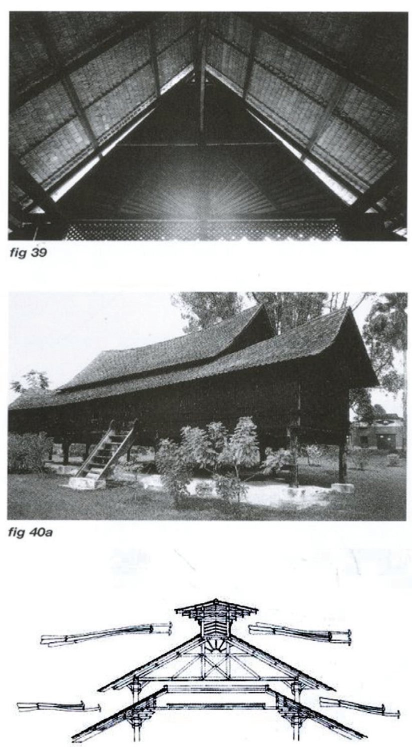


Figure 29: Interpretation of traditional Malay house

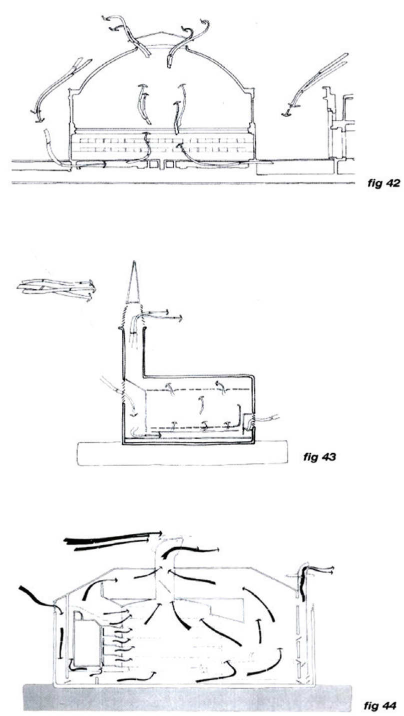


Figure 30: The British Museum Reading Room
Figure 31: The Bell Tower at Putney Church
Figure 32: Design for a theatre, 1872

pressure differential between the devices, producing more air flow through the building.

Ground Cooling Ventilation: the covoli (underground galleries)

An ingenious ventilative ground-cooling system was used in a group of sixteenth century villas near Vicenza, Italy. This villas are connected to them by underground galleries, Covoli, and from there distributed with the stack effect to the upper rooms through vents and openings. This methodology has more potentility to be integreated with contemporary active HVAC systems.

Solar-used Ventilation

Hot air rises so the system always works from bottom to top. Cool air comes in through low in-vents, is warmed, rises then goes out through high out-vents. This vertical movement of air is set in motion by the temperature differernce between the cool incoming air and the air under the skylights - this temperature differential must be at least 10℃. The warm air will not fight its way out against a breeze; therefore, as shown, out-vents are provided on each side of the roof ridge. For effective passive solar ventilation, the building should act as a thermal chimney, always allowing warm air to move up and out.

Double Skin

Double-skin facades offer several advantages. They can act as buffer zones between internal and external conditions, reducing heat loss. In combination with ventilation of the space between the two façades, the passive thermal effects can be used to best advantage. Natural ventilation can be drawin from the buffer zone into the building by opening windows in the inner facde. The stack effect of thermal air currents in tall buildings offers advantages over lower buildings. This eliminates potential security and safety problems caused by having windows that open, as well as wind pressure differentials around the building. Double facades

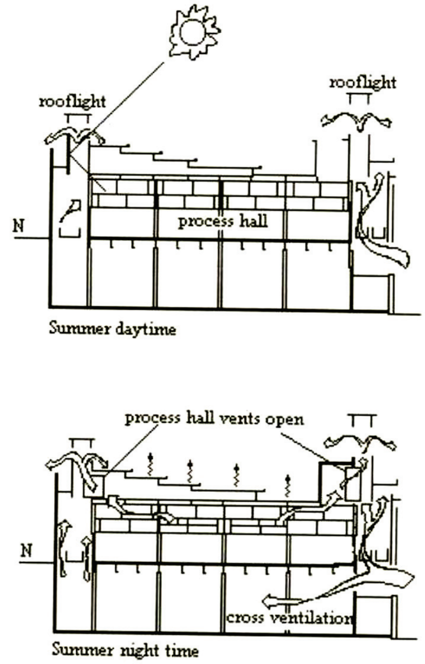


Figure 35: Short and Ford's Farsons Brewery

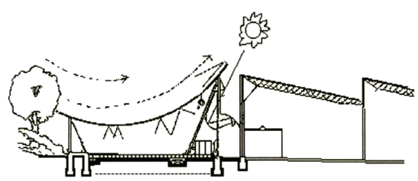


Figure 36: Piano's office building: cross section showing the airflow patterns around and through the building

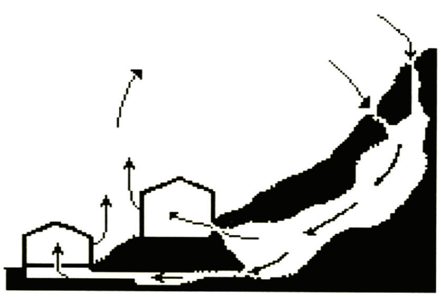


Figure 33: Scheme showing the connections and the airflow patterns between covoli and villas in the ground-cooling ventilation system

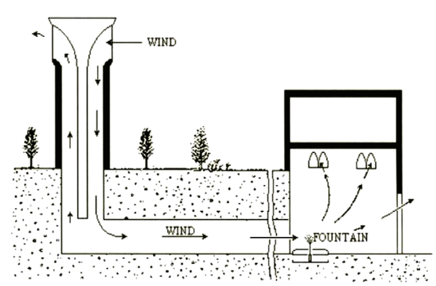
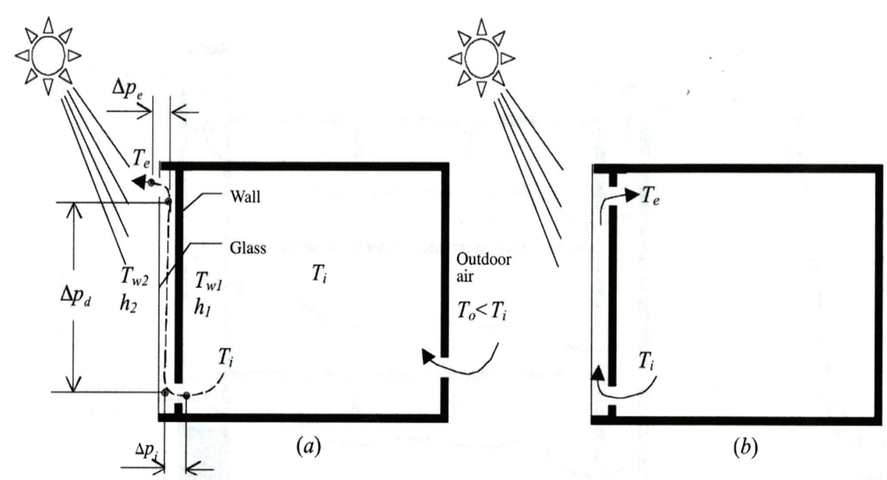
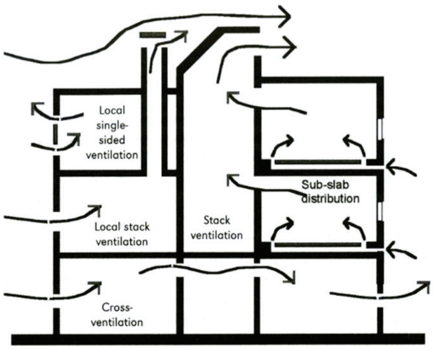


Figure 34: Windtower system associated with ground cooling



Source: adapted from Awbi (1998)

Figure 37: Solar collector used as (a) ventilation (b) heater



Source: Axley (2001)

Figure 38: Mixed natural ventilation strategies in a single building to satisfy local and global ventilation needs

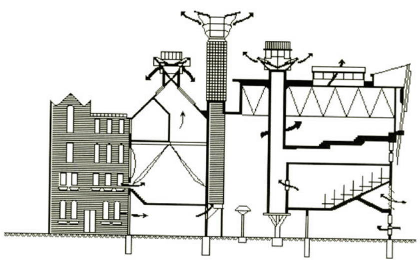


Figure 39: School of Engineering at Leicester, cross section showing the airflow through the chimneys

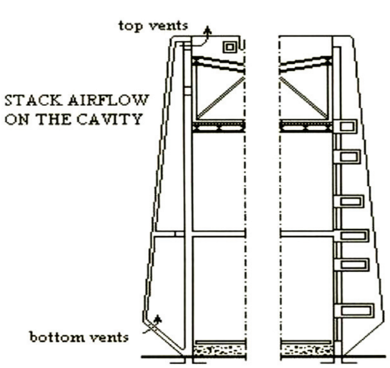


Figure 40: Nigerian Solar Energy Centre: the ventilated double-envelope cavity wall

Figure 41 . View of the building complex

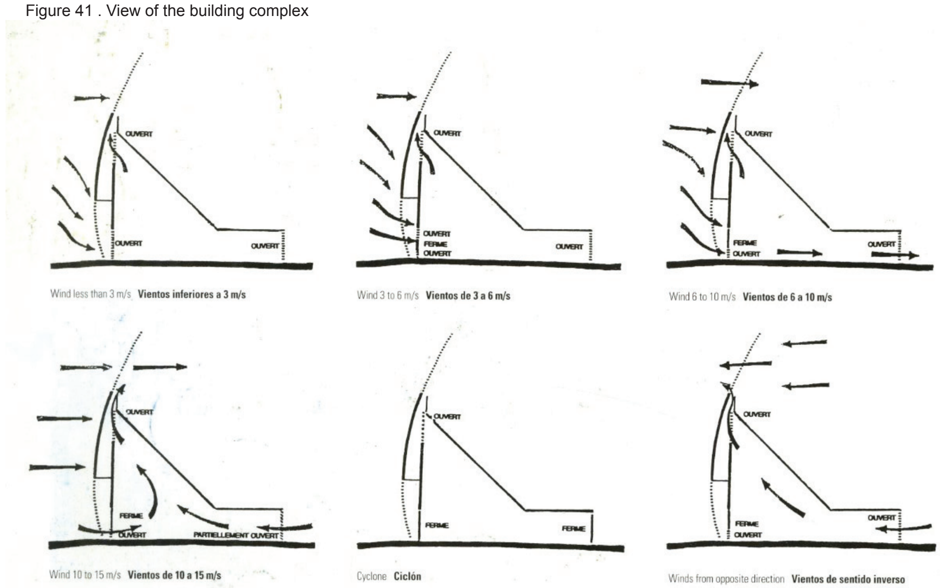


Figure 42. Conceptual ventilation diagrams

can be used for solar-assisted stack ventilation or balanced stack ventilation.

Hybrid Systems

Contemporary architecture has enhanced the ventilation system adapting a number of technologies in a building. From the traditional techinology of natural wind-driven building to the various device-supported systems, architects have tried hybridazation of the technologies.

Case Studies

Cultural Centre in New Caledonia

In a design intended to render homage to the traditional Kanak culture, but using contemporary language, Renzo Piano did true anthropological research into the nature of the “genius loci.” He responded to the breadth and specificity of the program by doing away with all Eurocentrist notions of concepts like culture or architecture.

The Cultural Centre is situated on a promontory to the east of Noumea. The constructional schema of its ten buildings is based on the evocation of the tall pines punctuating the landscape and the huts of the local Kanaks. Most of the ten single-theme spaces are the same height as a nine-story house, 28 meters. These give onto the street linking the three zones the village is divided into. The three tallest structures mark changes in program. The largest houses the exhibition space for artifacts of Kanak culture while the second

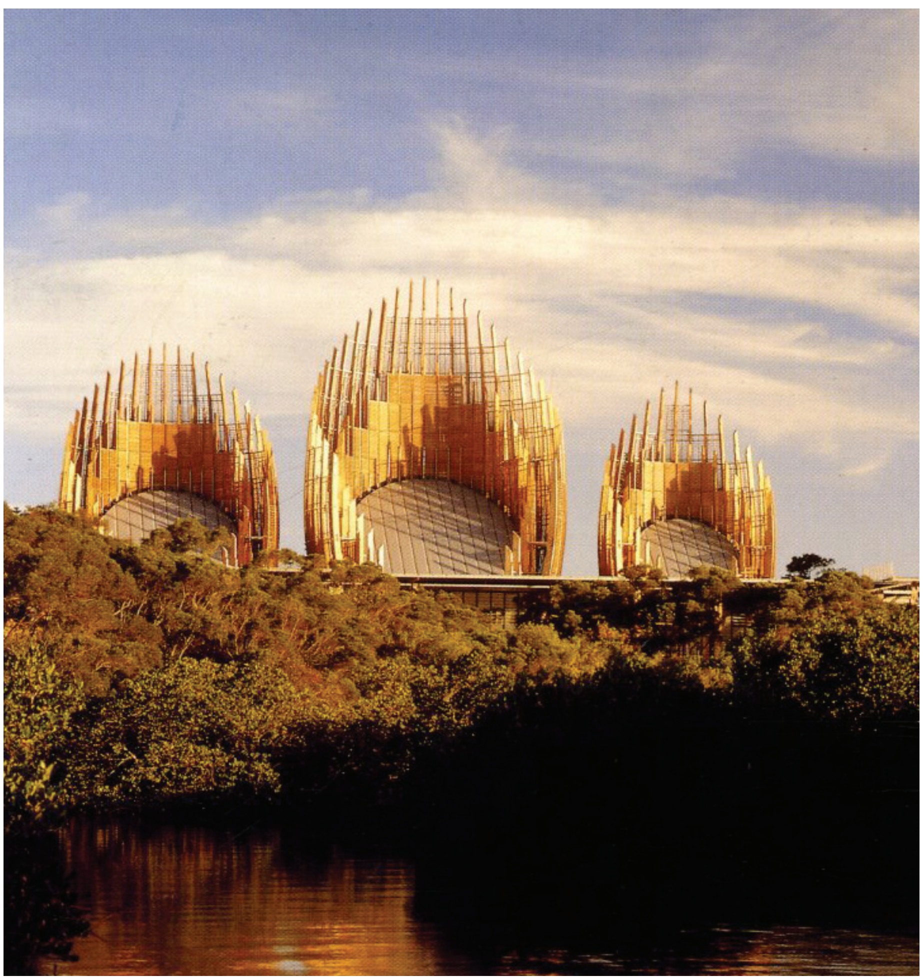


Figure 43. View from interior lagoon

Figure 44. Cross-braced wooden shell

largest contains a conference room and library for research work and the third points to the space used for dance, music, sculpture and painting related activities.

Because of New Caledonia’s mild climate, the decision was made to utilize natural ventilation as much as possible with operable glass panels. The structures have their back to the sea in order to best use the dominant sea breezes. As seen in Figure 53, great attention was given to the effect of winds of different direction and velocity.

Swiss Re Headquarters

This project was driven by a quest to create Britain’s first ‘environmentally progressive’ office tower. The scheme we see today emerged gradually as the design team analyzed reworked and refined various solutions to the building’s many component parts and its environmental systems. There are a couple main design decisions taken in order to influence the way air flows through and around the building.

The first and most obvious decision is the shape of the exterior, its iconic curved for which was used as a way to minimize drag, avoid unpleasant downdrafts and drive the system of natural ventilation as illustrated conceptually in Figure 56 and 57.

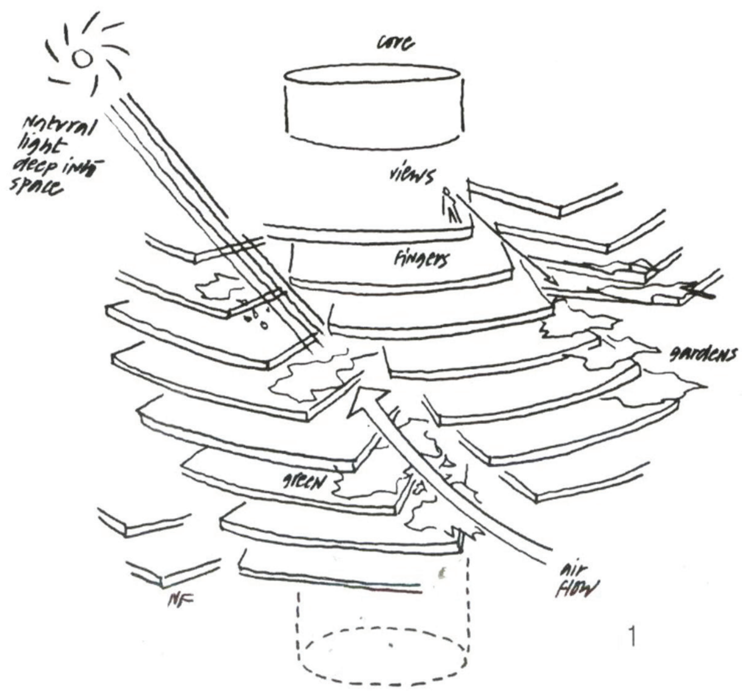


Figure 45. Atrium Diagram for the Spiral Ventilation Shaft

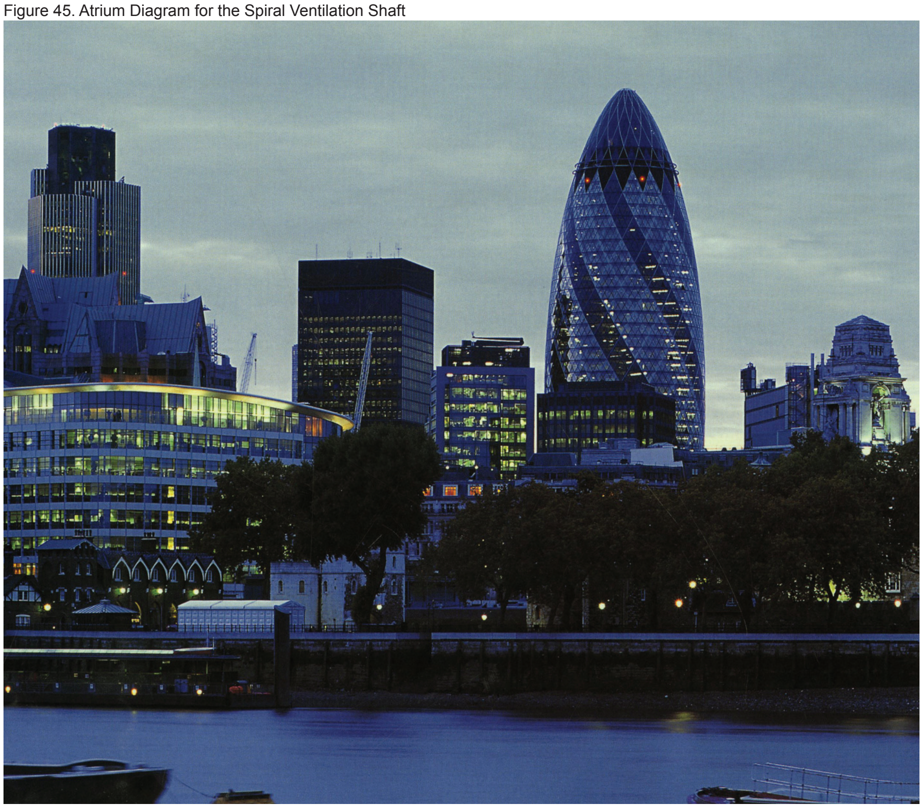


Figure 46. Night View of the Building

The speed of the air moving around the building is increased as it moves around the cylindrical profile which creates higher pressure differentials, thus greater potential for the use of natural ventilation. Computer simulations of air flow over a 3-D model were then used to fine tune the shape of the building.

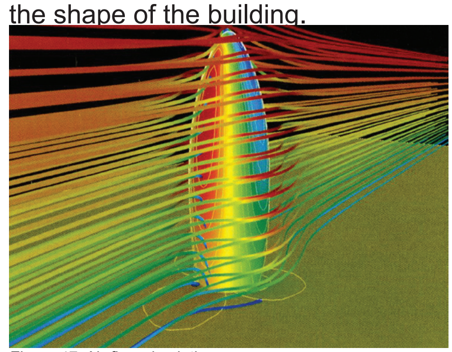


Figure 47, Air-flow simulation

Figure 48. View of Atrium

Figure 49. Curtain Wall Detail

Another important aspect used to control air flow is the use of clockwise rotating atria which let in air and create spiraling vertical shafts which allow air to rise through the building and between floors. Computer software that accounts for weather data selectively opens and closes groups of windows at the atria. These innovative systems keep the energy consumption for the buildings at half of what an average building of that size would consume.

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Figures